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WATER POLLUTION ABATEMENT PROGRAMME

THE CZECH REPUBLIC

PROJECT 5.1

Protection of Water Quality in Drinking Water Reservoires - Reduction of Detrimental Effects of Eutrophication by Biomanipulation

Project Report for Phase I and

Programme of Work for Phase II

NIVA - REPORT

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Abstract:

4 Czech and 3 Norwegian drinking water reservoirs have been discussed as a basis for cooperation between scientist from the two countries to exchange experiences on restoration of eutrophicated lakes and reservoirs. Feasibility studies will be carried out as a basis for action plans in which an optimal combination of of nutrient diversion, biomanipulation and other lake restoration measures will be analysed according to limnological, economical and technical premises.

4 keywords, Norwegian

1. eutrofiering
2. tiltaksplan
3. innsjørestaurering
4. biomanipulering

4 keywords, English

1. Eutrophication
2. Action plan
3. Lake restoration
4. Biomanipulation

Project leader

.......Bjørn A. Faafeng......

For the Administration

.............Dag Berge...........

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Protection of Water Quality in Drinking Water Reservoirs - Reduction of Detrimental Effects of Eutrophication by Biomanipulation

Project Report for Phase I and
Programme of Work for Phase II

Oslo, Norway
February 1993

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Preface

Project organization:

Czech Republic:

Water Research Institute, Prague (WRI-P)
Povodi Odry, Ostrava
Povodi Vltavy, Plzen
Povodi Ohre, Teplice
Hydrobiological Institute, Ceske Budejovice (CSAV)
Fisheries Research Institute, Dol u Libcic

Josef Fuksa (WRI) coordinates the Czech activities and will inform the Ministry of the Environment on the state of preparation and the demands of the 1993 project.

Norway:

Norwegian Institute for Water Research, Oslo (NIVA)
University of Oslo, Freshwater Ecology and Inland Fisheries Laboratory

Bjørn Faafeng (NIVA) coordinates the Norwegian activities.

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1. Objectives of the project

The aim of the project is to improve water quality in some eutrophic Czech reservoirs or lakes, especially those supplying drinking water, by biomanipulation: e.g. deliberate change of fish biomass and species composition. This measure may be a cost-efficient supplementary measure to nutrient diversion from households, agriculture and industry. A feasibility study will be carried out, as a basis for an action plan in which an optimal combination of nutrient divertion, biomanipulation and other lake restoration measures will be analysed according to limnological, economical and technical premises. The project will involve exchange of experience from the two countries and cooperation on practical investigations.

2. Project background and description

High input of nutrients to reservoirs and lakes causes excessive development of cyanobacteria and algae, with negative consequences both for the drinking water treatment process and for the quality of the produced drinking water. Substantial reduction of nutrient input is often a long-term and expensive process. With the proposed project we will study the feasibility of biomanipulation to improve the water quality of reservoirs, e.g. by change in species composition and biomass of the fish populations allowing the development of large-sized cladocerans *(Daphnia)*. These are effective feeders on phytoplankton and are able to maintain the algal biomass on a lower level than when large populations of pelagic fish are present. This method has been given substantial attention in the scientific and environmental management societies during the last years (see e.g. Biomanipulation - tool for water management, Kluwer Academic Press, 1990, 628pp). At present the key factor of success of the biomanipulation method seems to be the problems concerning a lasting change of the pelagic fish community.

Biomanipulation is studied both in the Czech Republic and in Norway, and joint efforts seem fruitful for cooperation in several reservoirs.

In the first part of this project, the project participants from both countries met in March to cleärify the actual problem in the Czech Republic before selecting reservoirs in which such a project is appropriate. These project proposals were presented for the steering committe meeting in May 1992. All available data on the reservoirs were presented at this meeting: catchment characteristics, hydrology, physical and chemical data on the reservoirs, phytoplankton, zooplankton and fish. This information serves as a basis to select the most appropriate reservoirs for this study. During this meeting the final budgets for the project should be developed.

Preparation of the final, detailed plans was carried out during the meeting in Oslo during October 1992 to allow start of the practical part of the project in spring 1993.

The following tentative time schedule has been worked out for this project:

May 1992	Meeting of steering commite of Czech - Norwegian Commission
Sept. 1992	Joint meeting for final planning in Oslo
Jan. - Dec. 1993	Sampling of reservoirs, echosounding, supplementary collection of pollution data
spring 1994	Development of report of situation and preliminary action plan
autumn 1994	Biomanipulation and/or other measures to improve water quality
1994 - 1996	Monitoring of water quality and evaluation of treatments

3. **Status of project January 1993**

In 1992 the groups of scientists from the two countries met to discuss and prepare plans for the project starting in 1993. As the project involved many persons and institutions, a major task was to coordinate these parties to give the basis for national funding and fruitful cooperation. No practical scientific activities were planned before 1993, except collecting relevant data on the different reservoirs and continuation of the monitoring programmes.

Three main activities within this project out during 1992 were:

- 30 March - 3 April: Norwegian visit to Czech reservoirs spring 1992
- 9 - 14 August : Participation on "International Conference on Reservoir Limnology and Water Quality", Ceske Budejovice
- 6 - 11 October Return visit of Czech partisipants to Oslo, Norway

3.1 Norwegian visit to Czech reservoirs spring 1992

Three reservoirs in the Ostrava region were visited by J.Fuksa and L.Havel together with B.Faafeng and Å.Brabrand during March/April 1992: Zlutice, Šance and Kruzberk. In the Ostrava region we also visited the Reservoir Moravka, but this reservoir was left out for further investigation in this project. In the Plzen district we visited the Zlutice Reservoir. During the visit the sampling strategy, parameters (fish stock assessment etc.) were discussed with responsible institutions (Sance & Kruzberk: P.Brezina at Povodi Odry, Zlutice: J.Duras at Povodi Vltavy) under the coordination of WRI-P (J.Fuksa and L.Havel). During the visit to Ostrava we also had discussions with J.Rehulka (fish parasites) and K. Gagyorova (phytoplankton).

The monitoring programme for 7 biomanipulation projects of WRI-P 1991 were sent to Povodi Odry and Povodi Vltavy.

The results of the monitoring of the three reservoirs of 1992 have been reported and sent to WRI-P and NIVA, including information of fish stock. Some additional information were exchanged later.

The state of monitoring of the reservoirs in 1992 has been described as follows:

A) Šance:
Vertical profile in the reservoir samples 5 times a year (chemical bacteriological and biological analyses, total phosphorus, chlorophyll-*a*). Inflows (Ostravice, Recice) and outflow (Ostravice under the dam) sampled monthly, total phosphorus determined only in the inflow sample.

B) Kruzberk:
Vertical profile sampled 6 times a year, for analyses see Šance. Inflow (Moravice) and outflow (raw water in waterworks). Sampled monthly, total phosphorus determined in both.

C) Zlutice:
Vertical profile sampled with the 3-4 weeks frequency, also the horizontal profile is sampled during the summer. Chemical analyses incl. total phosphorus and chlorophyll-*a*, analysis of seston and zooplankton (species composition, size distribution). Inflow (Strela) sampled monthly in several sampling profiles, chemical analyses include total phosphorus.

Fish stock in the reservoir is being evaluated in cooperation with the Fisheries Research Institute, Libcice (J. Vostradovsky).

The results from Kruzberk and Šance seem insufficient due to low sampling frequency and number of parameters. Only qualitative data on fish populations are available from the three Czech reservoirs.

3.2 Participation on "International Conference on Reservoir Limnology and Water Quality", Ceske Budejovice

Several of the project team members participated on the "2nd International Conference on Reservoir Limnology and Water Quality", Ceske Budejovice, Czechoslovakia, August 9 - 14 1992 with oral and poster presentations. Discussions were carried out on project no. 5.1 in the Czech - Norwegian "Water Pollution Abatement Programme" on the "Protection of Water Quality in Drinking Water Reservoirs - Reduction of Detrimental Effects of Eutrophication by Biomanipulation". The preliminary plans were presented to and discussed with representatives from the Hydrobiological Institute of the Czechoslovak Academy of Sciences, Ceske Budejovice (Vera Straskrabova, Vojtech Vyhnalek, Miroslav Macek, Jaroslav Vrba, Karel Simek and Josef Matena), Jindrich Duras from Povody Vltavy, Plzen and Jiri Vostradovsky from the Fisheries Reserch Institute, Dol u Libcice. Josef Fuksa from the WRI-P, also visited the conference and participated in some of the discussions.

3.3 Return visit of Czech partisipants to Oslo, Norway

During October 6 to 11 1992 a delegation of 8 Czech delegates visited Oslo to proceed the planning of the water pollution abatement program with their Norwegian counterparts. On the project 5.1 on biomanipulation the following persons took part: Josef Fuksa and Ladislav Havel from the WRI-P, Åge Brabrand from University of Oslo and Bjørn Faafeng from NIVA. A Proposal for a Work Programme for 1993 was prepared (see below).

A report from this workshop is published earlier (see "Progress report no.1, Results and recommandations from the workshop in Oslo 6-11 October 1992.").

4. Proposed work programme for 1993

The following were the results of the discussions in Oslo during October 1992 (se "Applications for phase II, The Water Pollution Abatement Programme, The Czech Republic, January 1993")

a: Zlutice:
The pattern of sampling and analysis is sufficient. After an evaluation of the results from the 1992 season (P.V., WRI-P, Hydrobiol. Inst. CSAV, NIVA, Univ. Oslo) some changes could be suggested, otherwise the present pattern of study should be maintained.

b: Šance and Kruzberk:
Sampling minimum in 4 weeks intervals is neccessary, also the determination of characteristics important for the biomanipulation must be included in the programme (P-total etc.).

After ending the 1993 season data will be evaluated and plan for 1994 could be prepared. The sampling etc. will be done by P.O., some special analysis should be done in cooperation with other institutions (Hydrobiol. Inst. CSAV, Fish. Res. Inst.).

c: Some of the reservoirs in Western Bohemia included in the 1991 Biomanipulation project of WRI-P will be chosen to be studied in this project. WRI-P will take contact with Povodi Ohre immediately.

d: Some of the reservoirs studied by the Hydrobiological Institute, Ceske Budejovice, might be included in this study. WRI-P will take contact with Hydrobiological Institute CSAV immediately.

e: WRI Prague will get information on technical equipment of Czech institutions involved especially on echolocation of fish. If it is found insufficient for the project purposes, fish stock estimations (echolocation part) will be performed by University of Oslo (Åge Brabrand).

f: During the algal bloom in Czech reservoirs samples of phytoplankton will be collected and tested by NIVA for toxic strains of blue-green algae.

g: Norwegian lakes in which biomanipulation has taken place, or is scheduled, should be studied parallell to the Czech reservoirs for comparison. The Norwegian coordinator will apply for economic support for such studies to the Norwegian Ministry of Environment.

5. Conclusions from the Norwegian participants after the first year of the project

- The success or failure of biomanipulation projects depend on many factors concerning the phosphorus-loading of the reservoir, the trophic state, flushing rate, fish population, food web interactions etc. A thorough feasibility study should therefore be implemented inluding identification, quantification and evaluation of pollution sources etc., before manipulations are carried out, cf. chap. 1: Objects of the project. These points are also stressed in a note from Hydrobiological Institute, Ceske Budejovice (Appendix IV). The water quality in several of the visited reservoirs may obviously benfit from reduced phosphorus loading from untreated domestic sewage, industry and agricultural runoff. Hence, phosphorus diversion, and also supplementary restauration measures, should always be taken into consideration before biomanipulation is carried out.

- Improved coordination of the different Czech institutions involved in this project is a premise for a successful binational project, to assure the best possible sampling, analyses and interpretation of the data from the reservoirs. Insufficient funding of the different institutions may also lead to serious lack of scientific consideration.

- At the visit to the Zlutice Reservoir in March/April 1992 we discussed different restoration measures to a dam/pond upstream the reservoir which might both prevent leakage of nutrients and toxic pollutants and improve the self-purification capasity. This might therefore add to the protection of the Zlutice Reservoir from prolonged pollution.

- Financing of a parallell Norwegian survey has been asked for, to support the idea of mutual exchange of ideas, experience and knowledge between the two countries. This would also include the geographical differences (climate, geology, biology, pollution level etc.) between the two countries. A limited number of Norwegian reservoirs/lakes (2-3) is suitable to be included in this project. The mesotrophic Lake Gjersjøen has been investigated for about three decennia, and monitoring in 1993 is already funded by local authorities and the Scientific Board (NTNF). We also have data from the nearby eutrophic Lake Årungen and simple monitoring programme is funded by the Scientific Board (FFT-Programme of NAVF). In both these lakes the predator fish pikeperch (*Stizostedion lucioperca*) has been introduced. Lake Isesjø, which is also suitable for this type of project, has been studied during the last years. However, no funding is expected for 1993 onwards from the local authorities. Supplementary funding of a Norwegian sampling and analysis programmes will be discussed with the Norwegian Ministry of Environment.

- Much less money was spent in 1992 in the Norwegian part of project 5.1 than expected since the scientific activities (sampling, analyses etc.) were postponed until 1993. The progress of the project will rely on the signals given from the Norwegian and Czech authorities on the proposed work programme.

APPENDIX I

Abstract of poster presented at the "2nd International Conference on Reservoir Limnology and Water Quality", Ceske Budejovice, Czechoslovakia, August 9 - 14 1992.

Longterm effects on different trophic levels in Lake Gjersjøen after introduction of the predatory pike-perch *(Stizostedion lucioperca).*

B.A. Faafeng[1] and Åge Brabrand[2]

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Introduction of the predatory pike-perch *(Stizostedion lucioperca)* to Lake Gjersjøen, SE Norway, induced major changes in the abundance of planktivorous fish, zooplankton community structure and phytoplankton species composition. Before the introduction of pike-perch in 1981 the Cyanobacterium *Oscillatoria agardhii* dominated the phytoplankton. Juvenile roach of size 6 - 11cm was the most dominant fish in the pelagic zone, being also the most important food item for the introduced pike-perch. A habitat shift occured for the juvenile stages of roach from pelagic to littoral areas, coinciding with the pike-perch introduction. Despite the nearly unchanged phosphorus concentration (18 - 20 mgP m^{-3}), the following main changes were observed in the lake during the years 1982 - 91: approx. 90% reduction in the abundance of pelagic roach, 30% increase in individual size of *Daphnia* although no increase in abundance, appearance of the macrofiltrator *Limnosida frontosa* and near extinction of the Cyanobacteria.

APPENDIX II

Description of the Czech reservoirs

Reservoirs Kruzberk and Šance supply ca. 50% each of the drinkingwater to the city of Ostrava.

Kruzberk Reservoir

Sampled and analysed by:	Povody Odry, Ostrava
Location:	Ca. 40 km west of Ostrava, outlet river: Moravice
Catchment area:	566.7 km^2
Land use:	Arable land 48%, forest 39%
Inhabitants in catchment:	39 000 mechanical/biological treatment in larger cities: Bruntal (63 000 P.E.), Rymarov (12 800 P.E.), Dvorce (1 850 P.E.)
Industry:	appr. 80 plants including: aluminium-, textile-, prefab. houses-, plastics industries. Hg in predatory fish? Erosion from dead forest areas probable.
Reservoir surface area:	3.165 km^2
Max. length:	ca. 6 km
Max. depth:	
Volume:	$45.965 * 10^6$ m^3
Altitude:	429 m.a.s.l.
Residence time (summer):	
P-loading:	
Water quality characteristics:	totalP (spring overturn): chlorophyll-*a* (summer peak):
Phytoplankton (dom.):	*Stephanodiscus hantzschii, Chlorococcoids, Crucigeniella rectangularis, Cosmarium reniforme*
Zooplankton (dom.):	*Bosmina longirostris, Daphnia longispina, Cyclops strenuus, Asplanchna sp., Keratella spp.,*
Fish species (dominants):	*Perca fluviatilis, Rutilus rutilus, Esox lucius, Stizostedion lucioperca, Alburnus alburnus*

A large dam is under construction upstream the Kruzberk Reservoir; Sleska Harta Reservoir. When this construction is finished severe erosion is expected during the first years of filling. Hence, temporary changes in the water quality in Kruzberk Reservoir are expected.

Šance Reservoir

Sampled and analysed by:	Povody Odry, Ostrava
Location:	Ca. 40 km south of Ostrava, outlet river: Ostravice
Catchment area:	145.4 km^2
Land use:	6.2% arable land, forest > 90%
Inhabitants in catchment:	1300 mechanical/biological treatment in Bila (500 P.E.) and Samchanka (376 P.E.)
Industry:	Saw mill, quarry
Reservoir surface area:	3.484 km2
Max. length:	7.6 km
Max. depth:	63.5 m
Volume:	$65.110*10^6$ m^3
Altitude:	504 m.a.s.l.
Residence time (summer):	
P-loading:	
Water quality characteristics:	totalP (spring overturn): chlorophyll-*a* (summer peak):
Phytoplankton (dom.):	*Asterionella formosa, Nitschia holsatica, Stephanodicus hantzschii, Synura uvella*
Zooplankton (dom.):	*Bosmina longirostris, Cyclops strenuus, Clathrulina elegans, Asplanchna sp.*
Fish species (dom.):	*Salmo trutta, S. gairdneri, Perca fluviatilis, Rutilus rutilus, Esox lucius*

In the Ostrava region was also the Reservoir Moravka visited during the spring 1992, but this reservoir was left out for further investigation in this project.

Zlutice Reservoir

Sampled and analysed by:	Povody Vltavy, Plzen
Location:	between the cities of Plzen and Karlsbad
Catchment area:	2154.8 km^2
Land use:	50% forest, 27% arable land
Inhabitants in catchment:	8000
Industry:	
Reservoir surface area:	1.3 km^2
Max. length:	4.3 km
Max. depth:	23.3 m
Volume:	
Altitude:	506 - 507 m.a.s.l.
Residence time (mean):	153 days
P-loading:	3-4 gP $m^{-2}year^{-1}$
Water quality characteristics:	meso-/eutrophic totalP (spring overturn): 40 - 60 mgP m^{-3} chlorophyll-*a* (summer peak): 15 - 40 mg m^{-3} Anoxic hypolimnion in August, high Mn conc.
Phytoplankton (dom.):	*Asterionella formosa, Synedra acus, Aphanizomenon gracile, Limnothrix redekei, Anabena flos-aquae*
Zooplankton (dom.):	*Daphnia galeata, Bosmina longirostris, Eudiatomus gracilis, Cyclops strenuus, Mesocyclops leuckarti*
Fish species (dom.):	*Perca fluviatilis, Scardinius erythrophtalmus, Coregonus spp., Rutilus rutilus, Stizostedion lucioperca.*

Reference: Duras, in press.

In the catchment of Zlutice we also visited a shallow reservoir/pond, which for a long time had been loaded with domestic sewage. Measures to avoid regeneration of nutrients and metals from the sedimentand optimal utilization of this pond for self-purification purposes to protect Zlutice was discussed.

Rimov Reservoir

Sampled and analysed by:	Hydrobiological Institute, Ceske Budejovice
Location:	
Catchment area:	488.5 km^2
Land use:	forest 50%
Inhabitants in catchment:	
Reservoir surface area:	2.11 km^2
Max. length:	13.1 km
Max. depth:	43 m
Volume:	$34.5*10^6$ m^3
Altitude:	471.5 m.a.s.l.
Residence time:	92 days
P-loading:	
Water quality characteristics:	beta-eutrophic totalP (spring overturn): 75-90 mgP m^{-3} chlorophyll-*a* (summer peak): 50 mg m^{-3}
Phytoplankton (dom.);	*Chrysococcus spp., Chloromonas spp., Asterionella formosa, Cryptomonas spp.,*
Zooplankton (dom.):	*Daphnia galeata, Bosmina longirostris, Diaphanosoma brachyurum, Cyclops vicinus*
Fish (dom.):	*Perca fluviatilis, Rutilus rutilus, Abramis brama*

APPENDIX III

Description of some Norwegian reservoirs/lakes

Reservoir Lake Gjersjøen supply drinking water to appr. 25 000 inhabitants of the catchment.

Lake Gjersjøen

Sampled and analysed by:	NIVA, University of Oslo
Location:	ca. 15 km south of Oslo
Catchment area:	84.5 km^2
Land use:	Arable land 15%, forest 69%
Inhabitants in catchment:	ca.30 000 domestic sewage deverted in 1971
Industry:	None
Reservoir surface area:	2.7 km^2
Max. length:	5 km
Max. depth:	63 m
Volume:	
Altitude:	42 m.a.s.l.
Residence time	appr. 3 years
P-loading:	0.3 gP m^{-1} yr^{-1} (1991) 2.5 gP m^{-1} yr^{-1} (1971)
Water quality characteristics:	totalP (spring overturn): 19 mgP m^{-3} chlorophyll-*a* (summer peak): 12 mg $m^{-3\ (0\text{-}10m)}$
Phytoplankton (dom.):	*Diatoma elongata, Asterionella formosa, Stephanodiscus hanzshii, Synedra acus, Aphanizomenon flos-aquae* (*Planktothrix agardhii* var. before 1982)
Zooplankton (dom.):	*Bosmina longirostris, Bosmina longispina, Daphnia cucculata, Thermocyclops oithonoides, Mesocyclops leuckarti*
Fish species (dominants):	*Rutilus rutilus, Perca fluviatilis, Esox lucius, Stizostedion lucioperca,*

Lake Årungen

Sampled and analysed by:	Agricultural University, University of Oslo, NIVA
Location:	ca. 20 km south of Oslo
Catchment area:	50.8 km^2
Land use:	Arable land 49%, forest 38%
Inhabitants in catchment:	?
	most of domestic sewage deverted
Industry:	None
Reservoir surface area:	1.2 km^2
Max. length:	3 km
Max. depth:	13.2 m
Volume:	
Altitude:	34 m.a.s.l.
Residence time	0.2 years
P-loading:	2.7 gP m^{-2} yr^{-1} (1991)
	5.3 gP m^{-2} yr^{-1} (1979-82)
Water quality characteristics:	totalP (spring overturn): 50 mgP m^{-3} (1992)
	100-400 mgP m^{-3} (1977-82)
	chlorophyll-*a* (summer peak): 66 mg m^{-3} (0-10m 1992)
Phytoplankton (dom.):	*Planktothrix agardhii, Microcystis aeroginosa, Synechococcus sp., Diatoma elongatum*
Zooplankton (dom.):	*Bosmina longirostris, Daphnia cucculata, Thermocyclops oithonoides, Mesocyclops leuckarti, Chaoborus sp.*
Fish species (dom.):	*Rutilus rutilus, Perca fluviatilis, Esox lucius, Stizostedion lucioperca,*

Lake Isesjø

Sampled and analysed by:	local authorities, NIVA, University of Oslo
Location:	ca. 90 km south of Oslo
Catchment area:	169km^2
Land use:	9% arable, 84% forest
Inhabitants in catchment:	320
Industry:	none
Reservoir surface area:	7km^2
Max. length:	6.5km
Max. depth:	22m
Volume:	
Altitude:	38 m.a.s.l.
Residence time	ca. 1 år
P-loading:	0.6gP m^{-2} yr^{-1}
Water quality characteristics:	totalP (spring overturn): 13-20 mgP m^{-3} chlorophyll-*a* (summer peak): 12-20 mg m^{-3}
Phytoplankton (dom.):	*Gonyostomum semen, Cryptomonas sp., Coelosphaerium spp.*
Zooplankton (dom.):	*Daphnia cristata, Diaphanisoma brachyurum, Eudiaptomus gracilis*
Fish species (dom.):	*Rutilus rutilus, Acerina cernua, Abramis brama Perca fluviatilis, Stizostedion lucioperca*

APPENDIX IV

Josef Matena & Vojtech Vyhnalek
Hydrobiological Institute
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Ceské Budejovice

Biomanipulation - proposals for a cooperative project.

1. Introduction

Hrbáček et al. (1961) found that biotic relations between the fish stock and the plankton are at least as important as the influence of the physical and chemical factors for the formation of the plankton association. The term " biomanipulation" for measures used to reduce the consequences of eutrophication was introduced by Shapiro et al. (1975). Under the term biomanipulation we now understand the top-down manipulation of the food web of an ecosystem. Primarily it means the manipulation of the fish stock. From the point of view of management of water bodies, the aim of biomanipulation can be defined as a cost-effective and nature-friendly improvement of some parameters of water quality.

There are several possible approaches how to influence the fish stock : poisoning (e.g. Shapiro 1982, Reinertsen & Olsen 1984), selective catch of undesirable planktivorous species (e.g. Benndorf et al. 1988, Kasprzak 1988), enhancement of the stock of piscivorous fish (e.g. Benndorf 1984, Edmondson & Litt 1984, Brabrand & Faafeng 1992), water level manipulation during spawning of planktivorous fish (Kubečka, unpubl.data).

The changes in fish stock (decrease of biomass of planktivorous species) induce a shift in size and even species composition of zooplankton. In an optimal case large Daphnia species (D.pulicaria) can replace smaler ones (D.galeata, D.cuculata). Large daphnids are generally more effective filtrators compared with smaler species.

Decrease of phytoplankton biomass, as a consequence of increased grazing of herbivorous zooplankton, is the most important expected effect of biomanipulation. A comparison of phytoplankton biomass before and after fish stock manipulation can be used as a criterion of a success of this effort. Further, the position under a 95% confidence limit of a chlorophyll-phosphorus relationship (e.g. Dillon & Rigler 1974) can serve as a suitable criterion of positive effects of biomanipulation (Hrbáček et al. 1978). In addition, effective biomanipulation can be indicated by an increased concentration of soluble reactive phosphorus in euphotic layer throughout the growing season (Hrbáček et al. 1978). Both last criteria are only applicable in phosphorus-limited systems.

In some cases the reduction of total phosphorus was observed (Reinertsen & Olsen 1984, Stenson et al. 1978, Scavia et al. 1986, Bjork 1985, Vright & Shapiro 1984). On the other hand, no reduction of nitrogen compounds can be expected as a result of biomanipulation.

Only recently the importance of microbial food web was recognized (Sherr & Sherr 1988). It plays an essential role in stabilizing the effects of food-web manipulations. In plankton of most of aquatic ecosystems, bacterial production is about 30% of primary production on an areal basis (Cole et al. 1988). If we assume growth efficincy of 10-50% (Pomeroy and Viebe 1988), planktonic bacteria process more than half of the organic C produced in aquatic systems. Vhile the response of zoo- and phytoplankton communities to manipulations of higher trophic levels have been documented, the responses of heterotrophic microbial processes remain largely unstudied. Bacteria are grazed by a wide variety of protozoans and metazoans (Pace 1988, Sanders et al. 1989). Changes at higher trophic levels may cascade to bacteria and protozoans via a number of pathways. For example cladocerans can, and do graze both bacteria and protozoans in addition to algae, whereas most copepods do not graze on bacteria (Stoeckner and Porter 1988).

Ve can expect two extreme situations in general:
(1) In sytems with low stock of planktivorous fish, large daphnids develop to a high standing stock, which causes a decrease in protozoan abundance resulting in low protozoan grazing on bacteria (Riemann 1985). Direct predation on bacteria by macrozooplankton could funnel a significant fraction of bacterial production up the food web (Pace et al. 1990). Naturally this situation develops during a clearwater phase of most of temperate freshwater bodies and is characterized, compared to the remainder of the season, by a significant drop in abundance of microheterotrops: by a factor 2-4 for bacteria, 5-15 for heterotrophic flagellates, and by temporal disappearance of ciliates (Šimek et al. 1990, Šimek and Straškrabová 1992, Vyhnálek et al. 1991). It follows that especially protozoans might be a sensitive indicator of the biomanipulation efficiency, as indicated in experimental enclosures (Riemann 1985).
(2) Under the same nutrient loading, a high abundance of planktivorous fish usually results in much higher phytoplankton biomass. Bacteria are grazed primarily by abundant protozoans, and then relatively little bacterial C will be transferred to higher consumers because of respiratory losses at each trophic step. Since this situation is more common and naturally develops during the spring or summer phytoplankton blooms, then the question arises: What is the fate of high primary production in the absence of large herbivors?

As recently reviewed by Sherr and Sherr (1992), heterotrophic nanoflagellates are as important in consuming ≥ 2 µm prey (mostly phototrophic cells) as they are in consuming picoplankton, and overall protistan herbivory rivals, or exceeds that of microcrustaceans. The real proportion of primary production consumed by protozoa in such systems, however, has scarcely been documented, as well as a strong shift in a size structure and species composition which might be expected. (Beaver and Crisman 1989, Sherr and Sherr 1992).

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2. Problems of biomanipulation

The current experience with biomanipulation is not consistent. The effect of decreased fish biomass on the structure of zooplankton was often documented, but sometimes without any positive effect on phytoplankton biomass (DeMelo et all. 1992). Reduction of phytoplankton biomass was achieved rather in small shallow waters than in larg stratified ones.

The increased grazing pressure of herbivorous zooplankton can favour large non-edible species, especially colonial blue green algae (Hrbáček 1964, Porter 1977, Lynch 1980). Therefore, the changes of size structure, species composition and seasonal development of phytoplankton can be the consequences of biomanipulation, but the average biomass remains unchanged (Benndorf et al. 1988). In shallow waters, biomanipulation can induce an excessive development of macrophytes (van Donk et al. 1990). The basic question of biomanipulation sounds: "How to prevent growth of non-edible phytoplankton species (or macrophytes) at high level of phosphorus and increased water transparency". From this point of view, the aim of biomanipulation (low biomass of phytoplankton at high level of phosphorus and sufficient light) can be understood as an "artificial situation". The tendency of ecosystem to return to the "natural situation" can be expected and therefore, a constant input of energy would be necessary to maintain and stabilize the biomanipulation effect.

It is known that biomanipulation is more efficient at low level of phosphorus input. In the case of high external (Benndorf et al. 1988) or internal (Lammens 1988) phosphorus load not all the desired improvements can be achieved. The "biomanipulation-efficiency threshold" seems to approach a value of about 0.6 g P m^{-2} $year^{-1}$ (Benndorf & Miersch 1988). Therefore, biomanipulation is recommended as an effective tool accelerating recovery of lakes after reduction of phosphorus loading (Søndergaard et al. 1990).

In stratified reservoirs used for drinking water suply, the water is often taken from the hypolimnion with generally low numbers of living algae (Vyhnálek 1991). Penetration of algal cells into the drinking water does not cause serious problems in this case. On the other hand, hypolimnion in deep reservoirs is often lacking oxygen with high concentration of manganese. It is possible to suppose that further positive effect of biomanipulation in stratified water bodies could be the improvement of oxygen conditions in the hypolimnetic zone as a consequence of reduced amount of sedimenting phytoplankton from the epilimnion. This could help to overcome problems connected with high concentrations of dissolved manganese in anoxic hypolimnion. Therefore additional criteria as oxygen and manganese concentrations should be introduced in stratified drinking water reservoirs.

There is only poor knowledge about relationships between effects of biomanipulation and technology of drinking water production. The most recent results on relationship between toxic compounds and trophic structure of aquatic ecosystems (Barica, pers. comm.) have to be taken into account. Higher acumulation of toxicants in organisms was found in oligotrophic than in eutrophic water bodies.

3. Czechoslovak experience

Two well documented large scale field experiments were performed in Czechoslovakia up to date. The Hubenov Reservoir was intensively stocked with salmonids during several first years after impoundment. A delay of the mass development of planktivorous species (mainly small perch, roach and common bream) was achieved. The phosphorus-chlorophyll ratio was outside of the confidence limits of the Dillon-Rigler's relationship (Hrbáček et al. 1978). In the Římov Reservoir an extensive program was applied for the reduction of planktivorous fish (seining, fyke nets, lowering the water level after spawning of roach and bream, stocking of piscivorous fish) in the period 1985-1989. The total fish stock decreased from about 600 kg per hectar to about 150 kg per hectar. The distinct effect on size structure of zooplankton was observed (Kubečka et al. 1990). The share of large daphnids (retained on a mesh 0.7 mm) increased from 1 % to 10 %. Nevertheless no change in the species composition of the zooplankton was achieved (unchanged dominance of D. galeata) and no reduction of the phytoplankton biomass could be proved. It seems that the critical biomass of fish stock for succesfull biomanipulation lies lower than achieved 150 $kg.ha^{-1}$. According to some literature date it might be even lower than 50 $kg.ha^{-1}$ (Mills & Forney 1983, Walker 1989, Jachner 1989).

More than 40 drinking water reservoirs in Czechoslovakia are managed with the aim to reduce the numbers of planktivorous fish and so to reduce the phytoplankton biomass in our country since 1978. To check the efficiency of this management the Hydrobiological institute together with co-workers from the River Authority Departments investigated nine of these reservoirs in 1991. Criteria were the relationship between the total phospuhorus concentration and the phytoplankton biomass, the dominance of the lager filtrators of the genus Daphnia and the share of large (>0.7 mm) specimens of Daphnia. It can be shortly summarized that no positive effect of biomanipulative measures was observed in any of the nine reservoirs investigated (Matěna et al. 1991). Our explanation is that the reduction of planktivorous fish was unsufficient. These results were confirmed by the qualitative investigation of the fish stock (Vostradovský et al. 1991).

In Czechoslovakia, a lot of experience on the effect of fish stock on the whole ecosystem was gathered from ponds (Fott et al. 1980). All these results confirm that positive effects of biomanipulation can be easier attained in smaller shalow water bodies and they can be maintained for a longer time there.

4. The aim of the project

- to test the effectivity of different approaches to fish stock reduction in different water bodies (latitude, lakes x reservoirs, size, depth)
- to test the influence of fish reduction on zooplankton structure, to find the limiting fish biomass for appearence of D. pulicaria
- to test the influence of fish reduction on phytoplankton biomass, structure and its controlling factors in different water bodies (latitude, size, depth) and at different phosphorus loadings
- to test the influence of fish reduction on microbial loop
- to test the influence of fish reduction on hypolimnetic concentrations of oxygen and manganese
- the general aim of the project is to find limits for biomanipulation

5. Proposals for further investigation/monitoring

- three reservoirs should be investigated Kružberk, Šance, Žlutice (comparison with lakes in Norway?, are these water bodies sufficient to cover the whole range - altitude, size, depths, phosphorus loading?)
- regular sampling in monthly intervals from the spring overturn (April) till September
- <u>sampling should include:</u>
    - phosphorus forms (total, particulate, soluble reactive) in the inflow and outflow, vertical and horizontal (2 profiles) distribution in the reservoir. Ve suppose that phosphorus is growth-limiting nutrient. This assumption must be proved at the beginning of investigation.
    - thermal and pH stratification in the reservoir, temperature of the inflowing water
    - phosphorus release from bottom sediments
    - C/P seston ratio and alkaline phosphatase activity as a measure of phosphorus limitation of phytoplankton
    - phytoplankton biomass (chlorophyll a), species composition, size structure with respect to the occurrence of blue-greens, vertical and horizontal stratification of phytoplankton
    - biomass, size and species composition of the zooplankton, fecundity estimation of the most important filtrators (genus Daphnia)
    - oxygen and manganese forms (dissolved, particulated) stratification along the reservoir

- microbial loop, counts and activities of bacteria and protozooa
- macrophytes - rough estimation
- fish stock biomass and species composition, growth rates of the dominant species before and after biomanipulation

- evaluation:

- phosphorus loading calculated for the whole reservoir and for the epilimnion separately using hydrodynamic calculations by means of dynamic simulation model DYRESM.

5. Time schedule

- Detailed investigation for 1 year before biomanipulation according to parameters mentioned above.
- Reduced investigation during biomanipulation (2 - 3 years)
- Detailed investigation for 1 year after biomanipulation

6. Possible problems

- do the selected waters cover the desirable range of size, depth and phosphorus loading ?
- technical problems with the reduction of the planktivorous fish

In the presented form the project proposal represents very broad approach to the problem of biomanipulation. It will be necessary to select areas of particular interest and specify the final version.

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